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Active Interrogation with a Short-Pulse Neutron Source

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Disclaimer

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1. Abstract

Active Interrogation is a method of radiation detection that uses a radiation generating source to induce nuclear fission so that an analysis can be made based upon the fission byproducts. A neutron source is typically used to cause fission which would cause a release of extra fission neutrons and gamma rays, as well as other fission fragments. A neutron source called a dense plasma focus (DPF) has been considered for active interrogation to determine the presence or absence of special nuclear material (SNM). The DPF features the ability to produce a number of nearly mono-energetic neutrons in a very short pulse, while conventional electronic neutron generators (ENG) can produce the same yield but over a much longer time. In this work, Monte-Carlo N-Transport Code (MCNP) was used to explore various configurations with two detection techniques that utilize the DPF's characteristic advantages. The first technique utilizes the time of flight of neutrons to discern SNM from other non-fissionable material. The DPF generates a fast pulse of 2.45 MeV neutrons which then leads to the emission of 0-10 MeV fission neutrons from SNM targets. A detector could then discriminate high-energy fission neutrons from low-energy source neutrons through time of flight. The second method considered the die away signatures from the target material and the neutron count as a function of time has a characteristic slope for SNM. With both of these methods, the modeled DPF enabled measurements that were not possible with the ENG.

Summary: MCNP6 was used to perform time of flight and die-away calculations for models utilizing the short pulse of the dense plasma focus (DPF). Time of flight has been found to be a functional method of determining the presence of special nuclear material (SNM), however due to the large standoff distance of the detector, there is a very weak prompt emission signal that would require a large amount of source neutrons to produce a verification of SNM. Die-away can show small differences in slope provided that the target is moderated. The slope differences observed in our MCNP simulations are not large enough to decisively discern SNM from benign material. We were unable to reproduce experimentally measured tail neutrons that are a result of multiplicity in a multiplying medium and unable to properly replicate spontaneous fissions over an appreciable time span. However, we did observe that with the short DPF pulse, differences in slope were observed earlier than in the case with the ENG. The DPF also demonstrated higher signal levels at the time the slope differences were present. Some modifications to the MCNP simulations are needed to more accurately reflect experimental benchmarks, but from the current, consistent parameters between the DPF and ENG simulations, the DPF should require fewer source neutrons to be able to provide a clearer presence/absence measurement with die-away analysis.

Simulation Input Parameters: Consistent MCNP input deck parameters in all cases

nps (histories run): `1e8` histories

time bin: Tallied every 1 shake (1e-8 seconds)

ToF-	`t4 1 59999i 60000`
DA-	`t4 1 79999i 80000`

Detectors: 2 He-3 Backpacks placed on the side

Volume per backpack:	`2.33e4`	cm^3
Density of He-3:	`3.76e-4`	g/cm^3

Tally/FM/SD/T: consistent with past inputs analyzing He-3 Backpacks (Vince/Han/Jen Inputs)

```
f4:n (82 182)
fm4 7.50751e-5 5100 -2
sd4 48676
t4 1 79999i 80000
```

Description of fields

F [tally number] [cells tallied over]

Fm [tally number] [atomic density] [material of He-3] [absorption cross section]

Sd [tally number] [volume of cell (x2 volume of He-3 tubes since 2 backpacks]

Description of tally

The f4 tally calculates the track length estimate for flux in n/cm^2 in a cell. (distance the particle moves in the cell). The cell being tallied over is cell 82 and 182 which are the active tubes of the He-3. The FM card then multiplies that F4 flux by the atomic density and the varying absorption cross section of the He-3. This considers in the energy dependence of the particles so the cross section changes as well. The tally is then multiplied by the volume of the cell, which is specified in the SD field. Finally, the end result is in units of (neutrons/source particle).

Source cards:

DPF

```
SDEF POS -25 0 50 PAR=n ERG=2.45 TME=d2
SP2 -41 1 5               $$ Gaussian Time Spread FWHM=1 shakes
```

**This is a mono-energetic (2.45 MeV) source with a Gaussian spread. The Full width half max is 1 shake (10 ns)

```
SDEF POS -25 0 50 PAR=n ERG=14.1 TME=d2
SP2 -41 1 5               $$ Gaussian Time Spread FWHM=1 shakes
```

**This is a mono-energetic (14.1 MeV) source with a Gaussian spread. The Full width half max is 1 shake (10 ns)

ENG

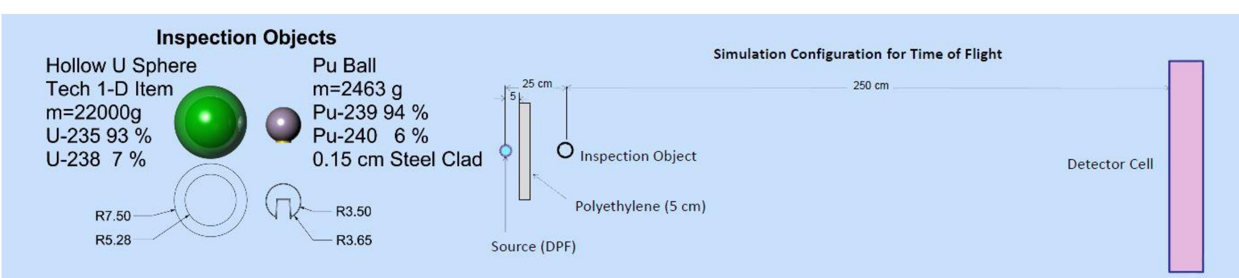
```
SDEF POS -25 0 50 PAR=n ERG=2.45 TME=D1
SI1 A 5 33305
SP1   1   1
```

**This is a mono-energetic (2.45 MeV) source with a 330 µs square pulse.

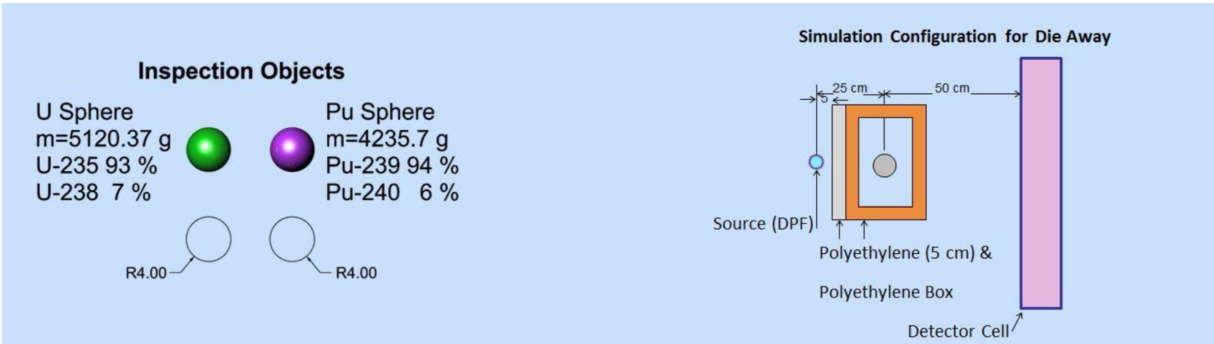
Objects and Setup

	Time of Flight	Die-Away	Material Properties
Plutonium	Pu Inspection Object m=2463g	4-cm r Sphere m=4235.70 g	ρ=15.8 g/cm^3 ^{238}Pu 0.014% ^{239}Pu 93.49% ^{240}Pu 5.973% ^{241}Pu 0.0071%
Uranium	Tech 1D Hollow Sphere m=21975g	4-cm r Sphere m=5120.37 g	ρ=19.1 g/cm^3 ^{235}U 93.0% ^{238}U 7.0%
Lead	Tech 1D Hollow Sphere m=13047g	4-cm r Sphere m=3040.05 g	ρ=11.34 g/cm^3 ^{204}Pb 1.4% ^{206}Pb 24.1% ^{207}Pb 22.1% ^{208}Pb 52.4%

Time of Flight



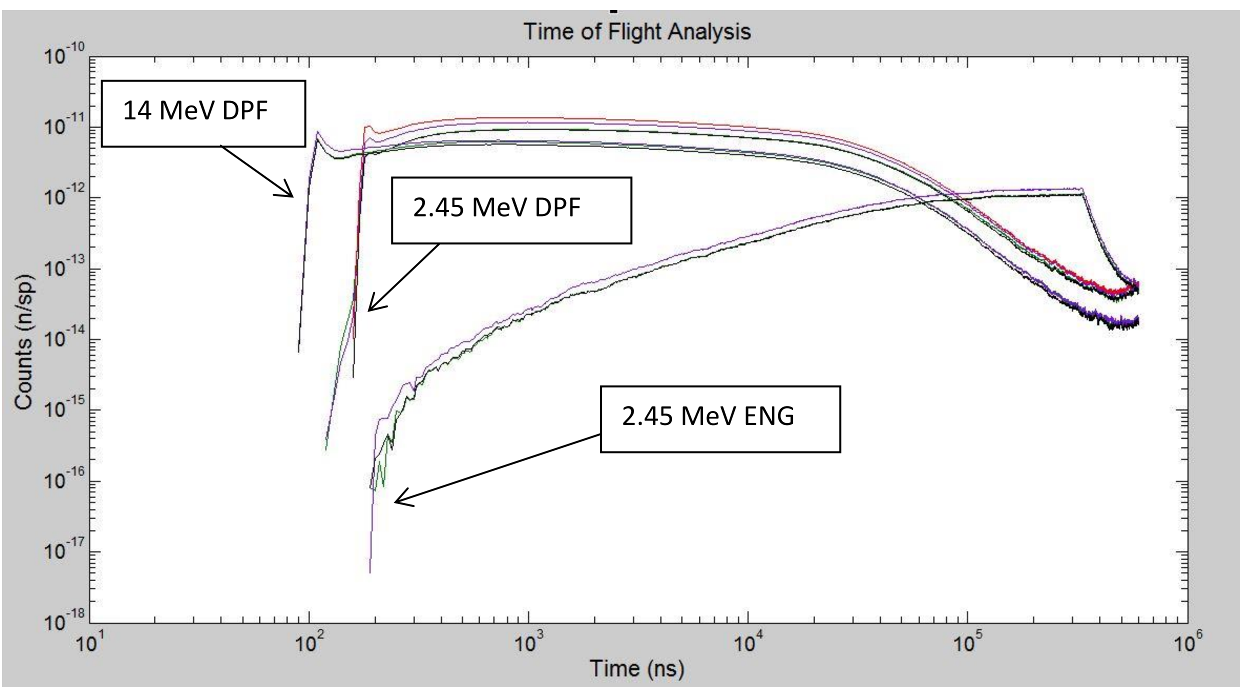
Die away



*Box is 19 cm thick on the front and back side.

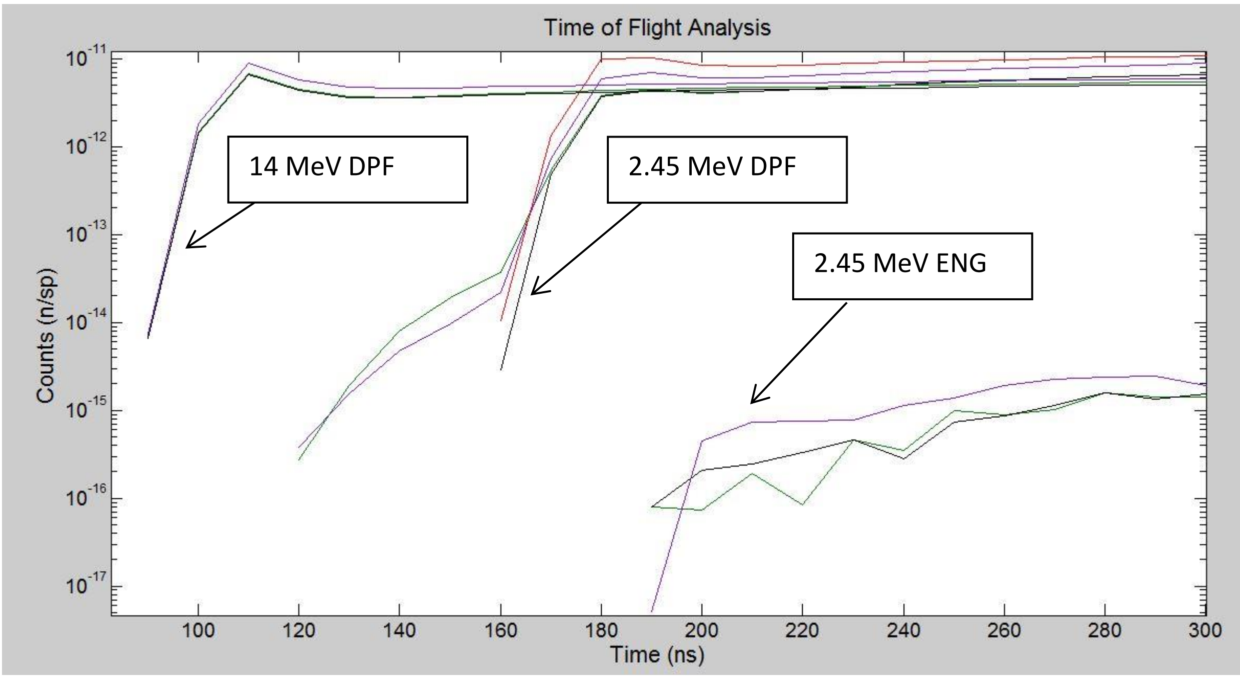
Results

Time of Flight
******
Green is Uranium
Purple is Plutonium
Black is Lead
Red is the source
******



General Comparison of time of flight signatures

A 14 MeV DPF was compared to a 2.45 MeV DPF and a 2.45 MeV ENG to see the effects of each type of source on the time of flight physics.



Zoom up of the signatures

The 14 MeV DPF source does not have any SNM indicating definition although it does have a stronger signal. The 2.45 MeV DPF source shows induced fission neutrons reaching the detector ~40 ns before source neutrons. The 2.45 MeV ENG source shows no discernable difference between SNM and Pb.

Considerations with Time of Flight

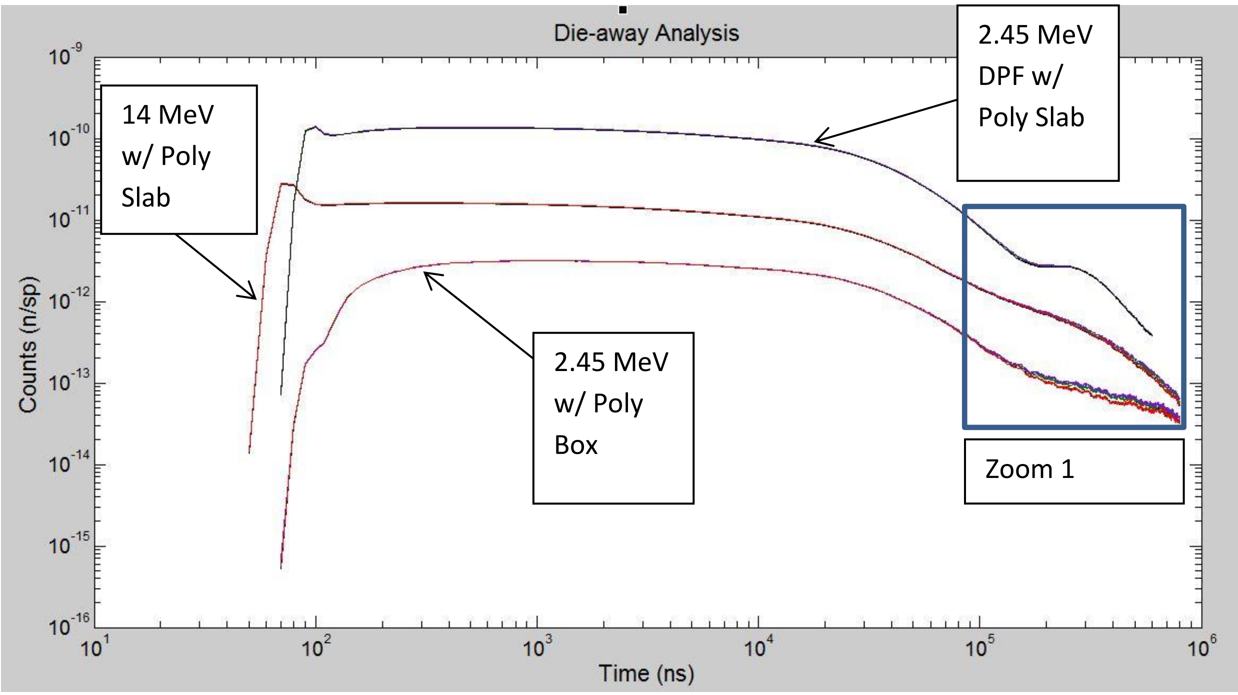
Time of flight is a valid model to use for presence/absence measurements albeit requiring a large amount of source neutrons to possibly determine SNM presence. Furthermore, a fast detector would be needed to pick up the short signal, but it would be able to decisively say that SNM is present.

Model Improvements

The detector standoff distance could probably be optimized to better fit the model. Furthermore, the Tech 1D item is massive compared to the Pu inspection object. However, when swapped to a 4 cm radius sphere (Die-away objects), the time of flight physics and the signal stayed the same. The shoulder was still there and the signal was dropped a small amount.

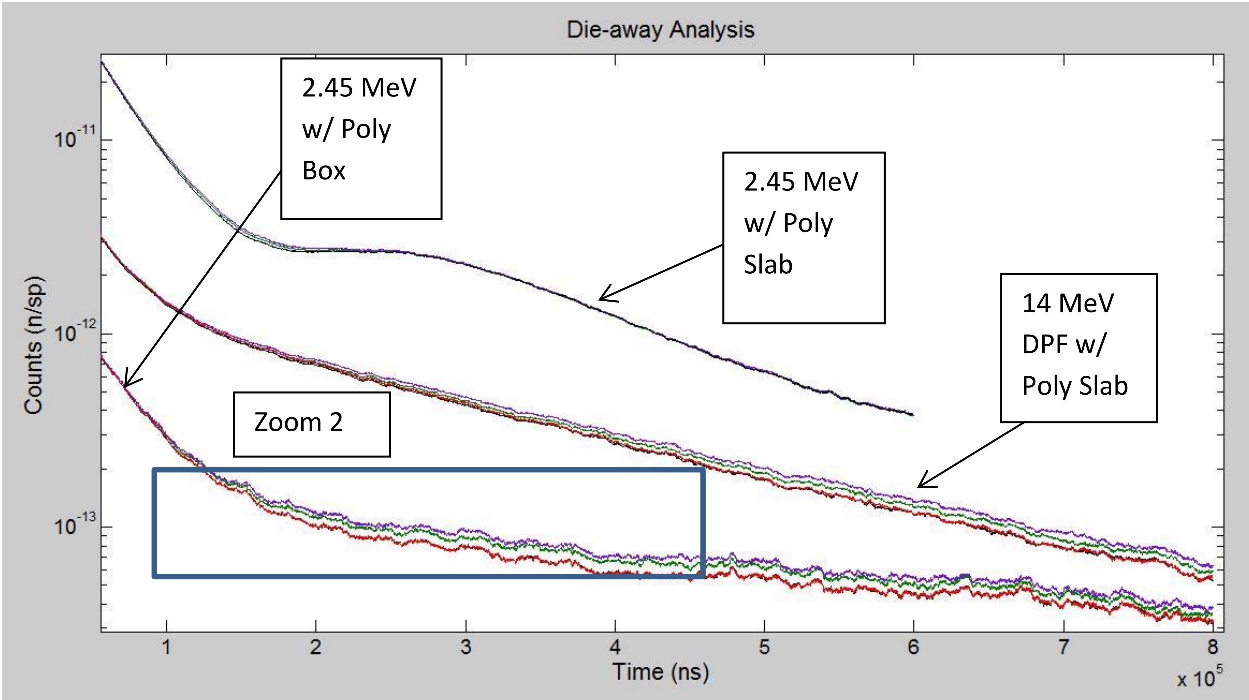
Die-Away
**

Green is Uranium
Purple is Plutonium
Black is Lead
Red is the source
**



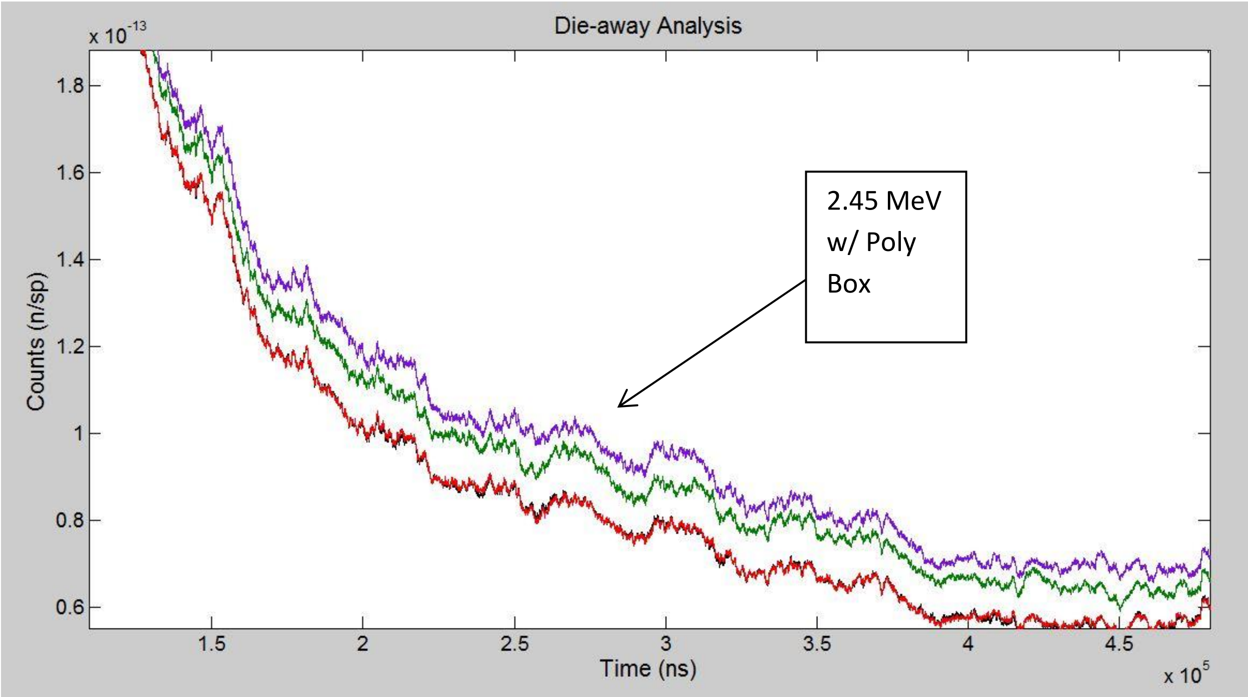
General Comparison of Die-away signatures

A poly slab designation means there is a 5 cm slab of poly ethylene infront of the source. A poly Box designation means 19 cm thick front and back wall of polyethylene surrounding the 4 cm radius sphere. The 14 MeV DPF with a slab and the 2.45 MeV DPF with a slab are both modeled as a comparison to each other. The graph shows that the 5 cm slab of poly ethylene does not moderate the source neutrons enough to show any divergence in the spectrum at the point of interest. However, when a significant amount of moderation is placed around the sphere (the poly box), a divergence becomes apparent at around 3e5 ns (300 µs). This is around 60 µs after the DPF pulse has stopped. Refer to the zoom panels for better definition



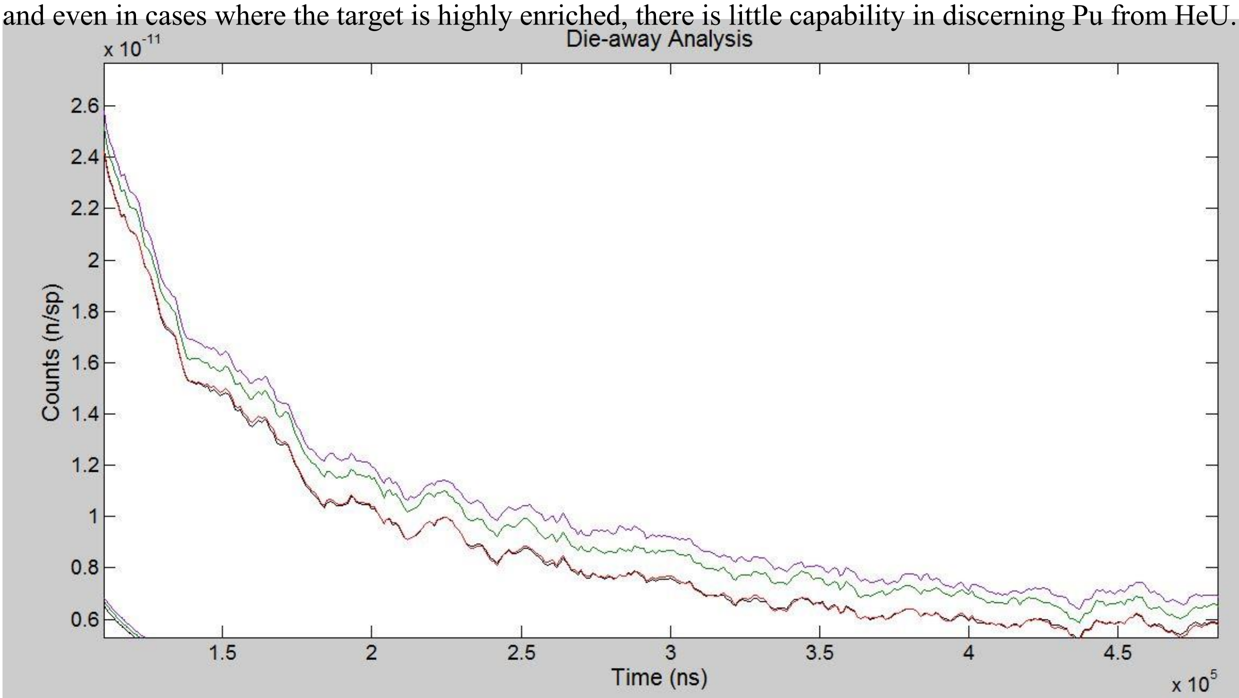
Zoom 1of Die-away signatures

The low moderated sources look extremely similar and do not deviate in a discernable manner.



Zoom 2of Die-away signatures

At this time there is some slope deviation in the model. This requires the target to be heavily moderated and even in cases where the target is highly enriched, there is little capability in discerning Pu from HeU.



Box car of Die-away signatures100x

With the data re-binned at 100x definition, the slope difference is more apparent and the signal is higher.

Considerations with Die-Away

The die-away signals are only apparent when the target is moderated and hence produces a very low signal. However, die away does not need fine time resolution and this model is binned once every 10 ns. Therefore, the signal can increase proportionally to the amount of scaling done by the time binning. By making time bins 10x larger, the signal would be increased to be 10x stronger. This could be done to levels of 100x larger for a time bin every 1 µs. At this time, the model does not properly reflect the long neutron tails that are present in experimental data. The neutron tails accentuates slope differences of different materials and directly affects the signal level of the system. Due to the absence of the tail, we are unable to estimate the approximate number of neutrons needed for analysis.

Model Improvements

Much more time is needed to consider all the aspects for fine-tuning the geometry to optimize the moderation needed for max signal and deviation. The room needs to be defined to more properly reflect room return. The detector could be moved closer to the object for better signal. Background radiation also needs to be added.

Conclusion

The DPF would likely be a superior candidate for neutron active interrogation as opposed to ENGs. For die-away, because the pulse is short, changes in slope of the time-dependent neutron signal are apparent earlier with the DPF source while yielding a stronger signal level. This implies that fewer neutrons would be needed to make the die-away measurement with the short pulse as opposed to an ENG. However, more work is needed to refine the model properly before the number of source neutrons can be quantified. Notably, our MCNP simulations would need to first reproduce the long tail associated with multiplicity in order for us to make this determination as well as to properly reflect the spontaneous fission emission.

Time of flight analysis for presence/absence measurements appears to be possible with the DPF, whereas it is not with an ENG. However, times of flight measurements are greatly affected by geometric factors that need to be further studied. Based on preliminary analysis, an extremely large number of neutrons would be needed to perform time of flight analysis.

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